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Strength of Cement Mortar

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THE EFFECT OF CLAY ON THE STRENGTH OF CEMENT MORTAR

BY

CLURE MORRIS POWELL

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

IN THE

COLLEGE OF ENGINEERING

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

CLURE MORRIS POWELL

ENTITLED THE EFFECT OF CLAY ON THE STRENGTH OF CEMENT MORTAR

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Civil Engineering

J. J. Richey Instructor in Charge

APPROVED: John P. Brooks

HEAD OF DEPARTMENT OF Civil Engineering

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The Effect of Clay on the Strength of Cement Mortar.

Introduction.

It is usual to specify that sand for cement mortar shall be clean, sharp, and coarse. Great precautions are sometimes taken to see that these specifications are enforced. This causes the contractor an extra expense in many cases. Sometimes the cost of a sand that would satisfy these specifications is prohibitive and sand containing a small percentage of foreign material, such as clay and loam, is used. A few experiments have been made to determine what effect a small per cent of clay or loam in the sand would have on the strength of cement mortar.

Among the first recorded experiments are those made by Mr. C. E. Clarke and published in the Transactions of the American Society of Civil Engineers, Vol. XIV, page 163. These experiments showed that a mortar composed of clean sand and Rosendale cement was no stronger after six months or a year than the same mortar when loam, to the amount of 10% of the sand, was added. He found that Portland cement briquettes were not weakened by substituting clay for from 2 to 8 per cent of the sand and their weathering qualities were not impaired in two and one half years. No special description of the sand is given.

In 1902 and 1903 a series of tests were made at Ohio State University to determine the effect of clay and loam

on the strength of cement mortar. The results showed that clay and loam substituted for various amounts of the sand in cement mortar were beneficial up to 15%. Of seventy-two curves showing the relation between the strength and the age of cement mortar when different percentages of clay or loam are used in the mortar only five curves show that the mortar was weakened by the substitution of clay for part of the sand. In eight cases out of twelve the mortar in which 15% of the sand used was clay or loam was the stronger. A striking feature of the results obtained from these tests was that the strength of mortar did not increase uniformly with the increase in the percentage of clay used. The sands used in these experiments were described as weighing 105 pounds per cubic foot, with 40% voids, and all passing a No. 30 sieve, and as weighing 102 pounds per cubic foot, with 40% voids, and passing No. 12 sieve. Both sands were washed.

Some tests were made in the laboratories of the Bridge and Building Department of the Chicago, Milwaukee, and St. Paul Railway with different mixtures of sand, clay, and cement. The clay did not decrease the strength of the 1 : 2 mixture, and in the 1 : 3 mixture the addition of clay in small quantities was beneficial in all cases.

A series of experiments was made at the University of Kansas to determine the effect of clay on the strength of cement mortar by using standard sand and common red clay. During the construction of the Galveston Breakwater a series of tests was also carried on with clay, standard sand, and cement.

The results of the tests above referred to, shown graphically in Plates 9 and 10, indicate that for each sand there is a certain maximum percentage of clay which gives a maximum strength to the mortar. There is no uniformity, however, in the increase of strength due to the addition of the various percentages of clay. The effect of any certain percent of clay is different for different sands. The results obtained for the different ages of the mortar vary and the effect of different percentages of clay on the strength of the mortar is less marked as the age increases. From the description of the sands which were used in these tests, no relation can be established between the kind of sands and the manner in which the clay affected the strength of the mortar.

All the tests previously made were tension tests. No compression tests have ever been made so far as the writer has been able to learn. Cement mortar is used in compression more than it is in tension. Therefore it was considered desirable to make both tension and compression tests. In selecting the sand used, as great a difference in the mechanical composition of the two sands as was possible governed the choice. This selection of sand would tend to show whether the mechanical composition of the sand has anything to do with the effect of clay on the strength of the cement mortar.

Description of Materials Used.

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Cement.-

The cement used in the tests was Chicago A A.

Sand.-

Two kinds of sand were used in the tests. Both were clean and free from all foreign material. All sand passed a No. 10 sieve.

One sand was fine with the different sizes poorly graded. It would not be considered good sand for making concrete. For convenience this sand will be referred to as No. 1 sand.

The other sand was Wabash River sand and is much used in building and concrete work. It is coarse and the different sizes are well graded. This sand will be referred to as No. 2 sand.

The voids, as determined in the usual manner, were for the No. 1 sand 40.2%, and for the No. 2 sand 35.2% .

The mechanical analyses of the two sands are shown in the following table. These are also shown graphically in Plate 1. The results are the average of two analyses made at different times.

Table No. 1.

MECHANICAL ANALYSIS OF THE SANDS.

------C------

No. 1. Sand.

No. of sieve.	16	20	30	40	60	74	100	150	200	Passing 200	Total.
Percent Retained on each Sieve.	5.62	1.85	11.41	23.85	42.17	6.44	6.63	1.25	.26	.52	100.
No. 2. Sand.											
Percent retained on each Sieve.	26.06	6.50	26.08	16.24	16.85	3.03	3.48	.86	.31	.59	100.

Clay.-

The clay used in the tests was a shale containing about seventy-five per cent of hydrous silicate of aluminum with uncombined silica and a small percentage of other constitutents. It was first dried and ground in a ball mill as fine as the cement.

Description of Methods of Working.

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The methods used in making the specimens was that recommended by the American Society of Civil Engineers. The materials were first mixed dry, a 1 : 3 mixture by weight being used. The clay added was a percentage of the sand and the ratio of one part of cement to three parts of aggregate was always maintained. The clay was added in amounts of 2%, 5%, 7%, 10%, and so on up to 20%.

The amount of water added was such as to keep the same plasticity in the various mixtures. This amount was determined by experiment for some of the mixtures and the others taken from a curve plotted from these results. This curve is shown in Plate 2.

The tension specimens were the standard briquettes and the compression specimens were 3-inch cubes. Both were moulded by hand. The specimens were allowed to set in the moulds under a damp cloth for 24 hours and then placed in water until tested. The cubes, however, were taken out of the water 30 hours before being tested. The compression faces were bedded in plaster of paris to give a more even bearing to the compression faces. A Riehle briquette testing machine was used for breaking the tension specimens, and the cubes were tested in a 100 000 pound machine of the same make.

The tests were made at 7, 28, and 90 days in the case of the tension specimens and for the compression specimens at 28 and 90 days.

For the tension tests 5 briquettes were made for each age for each percentage of clay. All fifteen briquettes were made at the same time. Three cubes were made for each age for each percentage of clay, for the compression tests.

The average of the results for each set of the tests was used as the value for that test. The probable error for each set was calculated from the formula ,

$$\text{Probable Error, } E = 0.6745 \sqrt{\frac{d^2}{n(n-1)}}$$

in which d is the difference between any result and the mean for the set to which it belongs, and n is the number of specimens. These results are given in the tables below.

Table No. 2.

TESTS SHOWING THE EFFECT OF CLAY ON THE TENSILE STRENGTH OF 1 : 3 PORTLAND CEMENT MORTAR.

Results Are the Average of 5 Standard Briquettes.

Percent of Clay.	Ultimate Strength in Pounds per Square Inch.											
	No. 1 Sand.						No. 2 Sand.					
	7 days	E	28 days	E	90 days	E	7 days	E	28 days	E	90 days	E
0.0	102	3	188	1	226	7	185	2	255	6	313	11
2.	108	5	200	8	243	5	185	6	220	5	315	3
5.	139	3	218	3	275	1	198	1	253	4	349	7
7.	153	2	236	4	283	5	207	7	245	5	349	11
10.	157	2	230	4	283	2	200	7	270	6	338	8
12.	175	3	248	7	309	5	203	1	312	9	375	8
15.	171	10	236	3	279	3	203	1	244	4	334	5
17.	145	2	213	6	268	11	175	6	202	0	274	11
20.	151	9	224	1	243	4	154	6	215	4	291	1

E is probable error(See page 7.)

Table No. 3.

TESTS SHOWING THE EFFECT OF CLAY ON THE COMPRESSIVE STRENGTH OF 1 : 3 PORTLAND CEMENT MORTAR.

Results Are Average of 3 Three-inch Cubes.

Percent of Clay.	Ultimate Strength in Pounds per Square Inch.			
	No. 1 Sand.		No. 2 Sand.	
	28 days.	90 days.	28 days.	90 days.
0.0	927	1560	1680	2207
2	1047	1585	1858	2353
5	1197	1968	1710	2415
7			2037	2577
10	1175	1751	2006	2125
12			1822	2135
15	1251	2032	1552	1718
17		1819	1547	2507
20	1212	2201	1249	2310

Results.

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In general it may be said that the results of the tests show that small quantities of clay, at least when finely ground, do not decrease the strength of a 1 : 3 Portland cement mortar, but increase its strength very appreciably. The tests extended over a period of ninety days and the results do not show what effect clay would have on the strength of the mortar after this time. A study of the results shows also that the clay affected the tensile and compressive strength of the mortars differently. The results of the tests are shown graphically in Plates 3 to 8 inclusive.

Effect of Clay on the Tensile Strength.

No. 1 Sand.

The results show that, with the poorly graded sand, the clay increases the strength for all percentages of clay that were used in the tests. The tendency of the clay with this sand was to increase the strength of the mortar uniformly with the increase in the amount of clay up to 12%. Any increase over this amount shows a corresponding decrease in the strength. However, with 20% of clay the mortar was still stronger than with the sand alone.

No. 2 Sand.

There is no uniformity in the increase in the strength of the mortar with the increase in the amount of clay with the well graded sand. The mixture containing 12% of clay showed the

greatest strength. The mixtures containing 15% of clay were weaker than the mortar made from sand and cement alone.

Effect on the Compressive Strength.

No. 1 Sand.

The results of the tests with the poorly graded sand show no uniformity in the increase or decrease of strength with the increase in the amount of clay. The greatest strength was obtained from the mixture containing 20% of clay.

No. 2 Sand.

The results of the compression tests with the well graded sand also show no uniformity in the increase or decrease of strength with the increase in the amount of clay. The mixture containing 7% of clay gave the greatest strength.

Conclusion.

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The results of the compression tests are probably not as nearly correct as the results of the tension tests, owing to the fact that the cubes are subjected to a greater variation in the conditions which affect the strength in the making and testing of the specimens. The No. 1 Sand was inclined to roll in the moulds, like standard Ottawa sand, when the mixture contained no clay. The addition of clay made the mixture more easily compacted and this no doubt affected the results obtained with this sand. The probabilities are that the compression tests were more affected by this tendency of the clay to make the mixture easily compacted than were the tension tests. The clay affected both sands in this respect to a noticeable extent. The conclusions by other observers made from earlier tests were that clay in quantities not exceeding 12 or 15 percent increased the strength. The results obtained from the tension tests herein reported seem to bear out these conclusions. Although the earlier experiments show that short time tests are not of as much value as long ones in this connection, the results of the compression tests indicate that only about one-half as much clay is needed to give the mortar a maximum compressive strength as is needed to give it the maximum tensile strength.

The exact action of clay on the hardening of mortar has not been determined; the probabilities, however, are that the

action is entirely physical as there is no known chemical reaction between the clay and Portland cement during hydration. The clay possessed no hydraulic properties. Those who have investigated the chemical reaction involved in the hardening of cement conclude that if the effect of the clay is other than physical it must be brought about by some obscure catalytic or electrolytic action which may either alter the speed of crystallization or the size and arrangement of the crystals or affect in some unknown way the colloidal action.

It is apparent that the work involved in the study of the effect of clay on the strength of cement mortar and concrete is too great to be accomplished in the time available for a student's thesis. In order to come to any conclusions more definite a greater number of tests would be required to eliminate as far as possible the variations in the conditions which affect the strength of the mortar. The increments by which the percentages of clay in the various mixtures of sand, clay, and cement are increased should be much smaller, and the tests should extend over a period of time long enough to eliminate the variation in the strength of the mortar due to age.

CURVES SHOWING THE MECHANICAL ANALYSIS OF THE SANDS USED IN THE TESTS

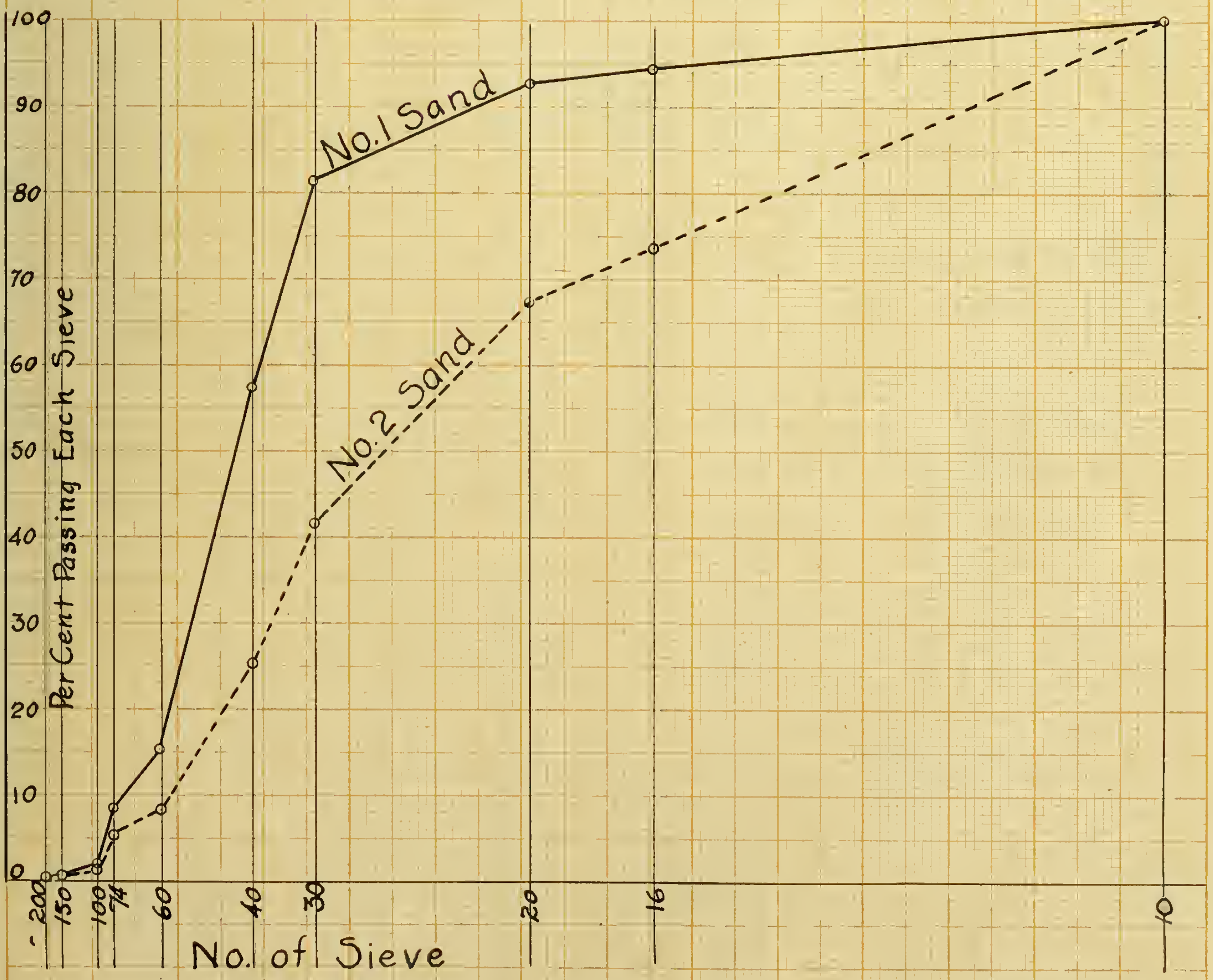


Plate 1

CURVE
SHOWING PER CENT OF WATER REQUIRED TO GIVE SAME PLASTICITY TO 1:3 MIXTURES CONTAINING VARIOUS PERCENTAGES OF CLAY

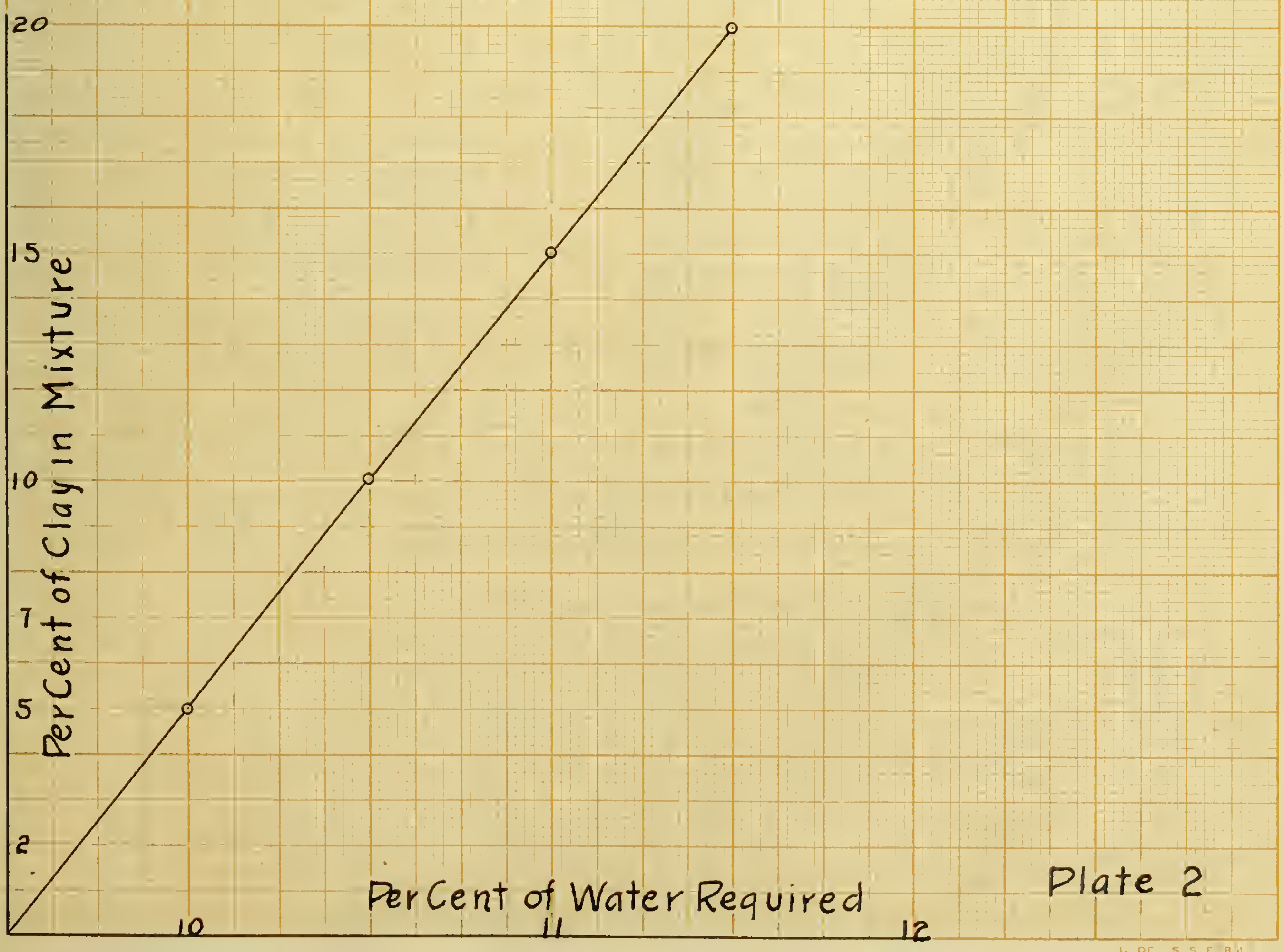
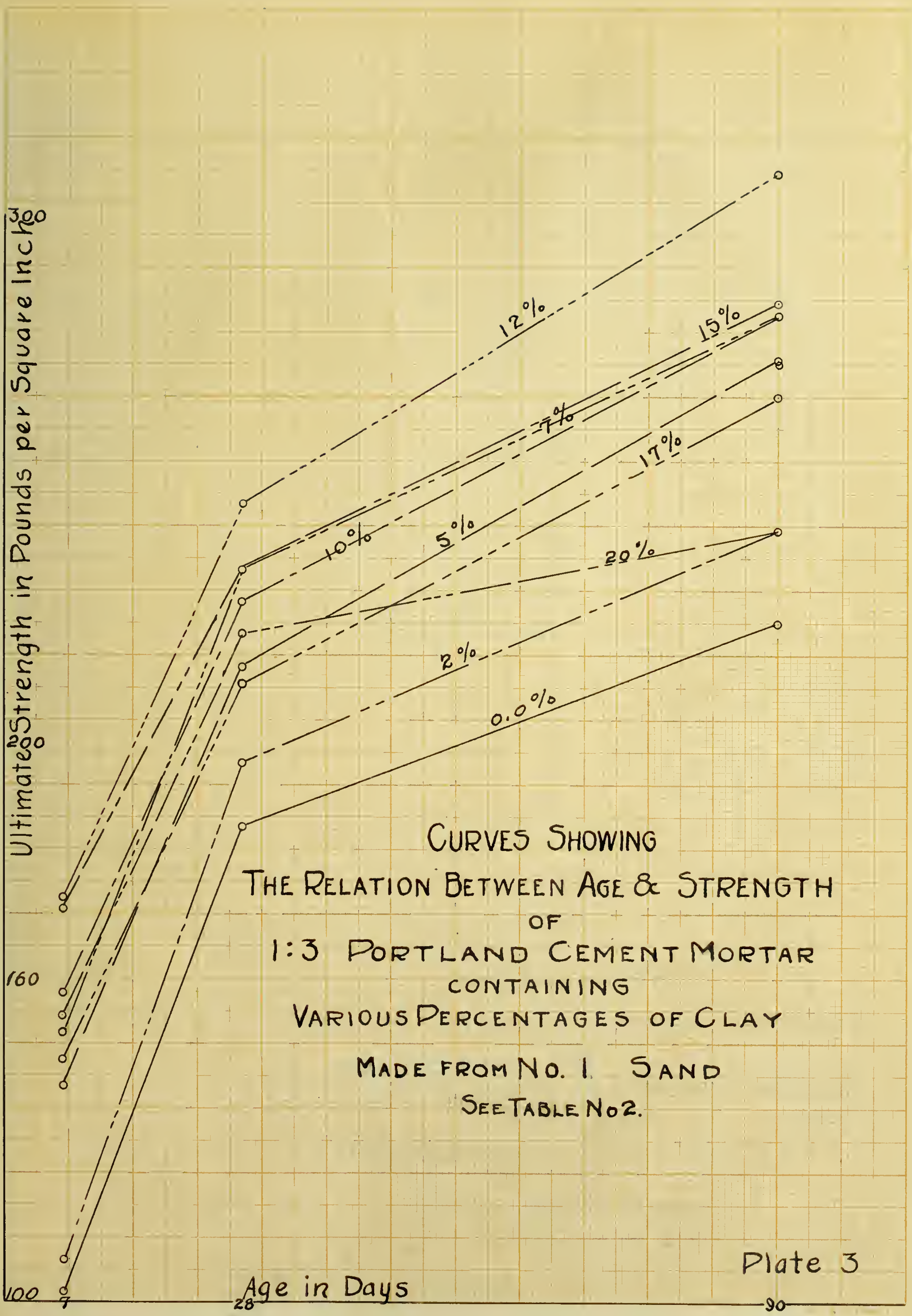
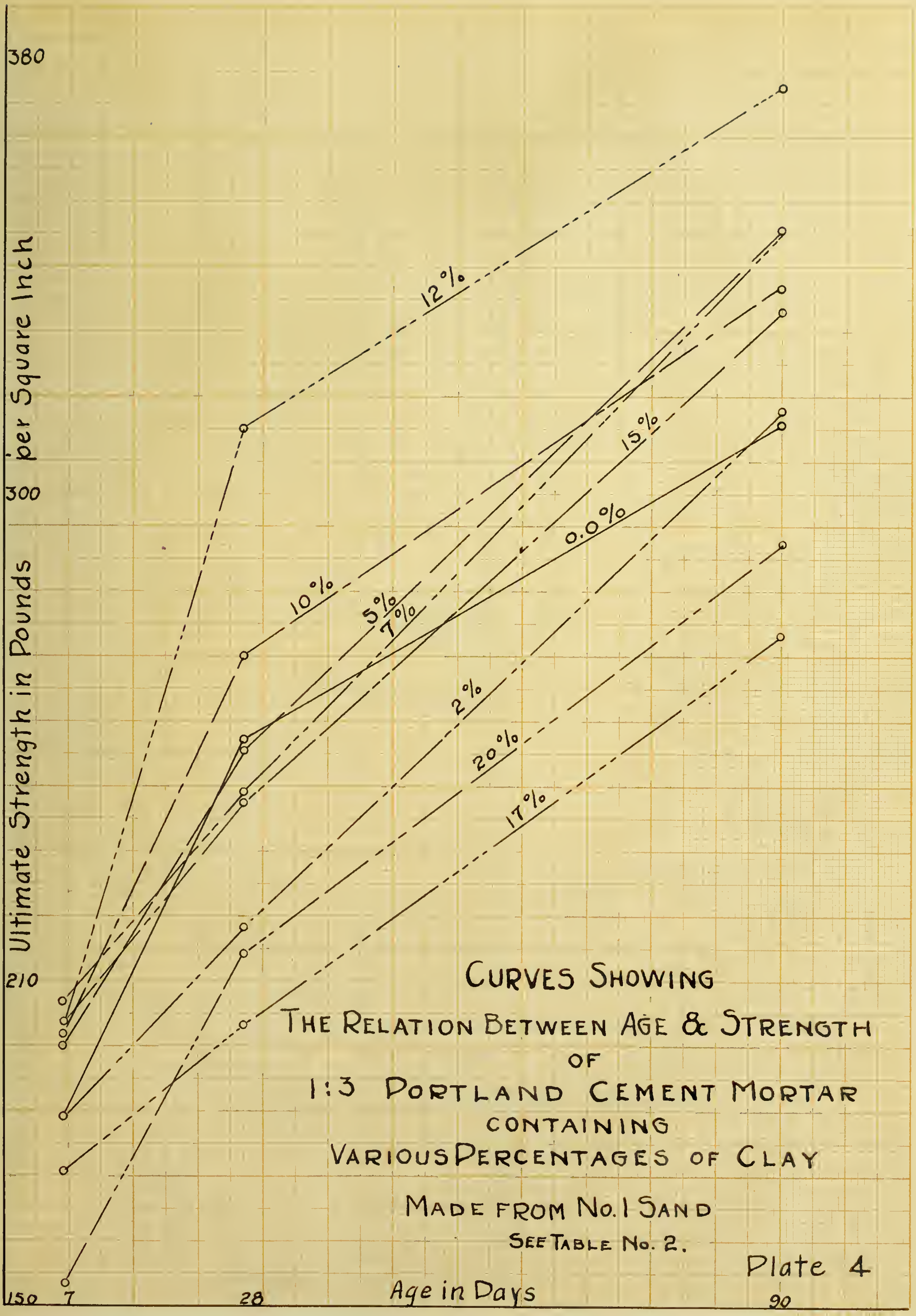


Plate 2



CURVES SHOWING
THE RELATION BETWEEN AGE & STRENGTH
OF
1:3 PORTLAND CEMENT MORTAR
CONTAINING
VARIOUS PERCENTAGES OF CLAY
MADE FROM NO. 1 SAND
SEE TABLE NO 2.

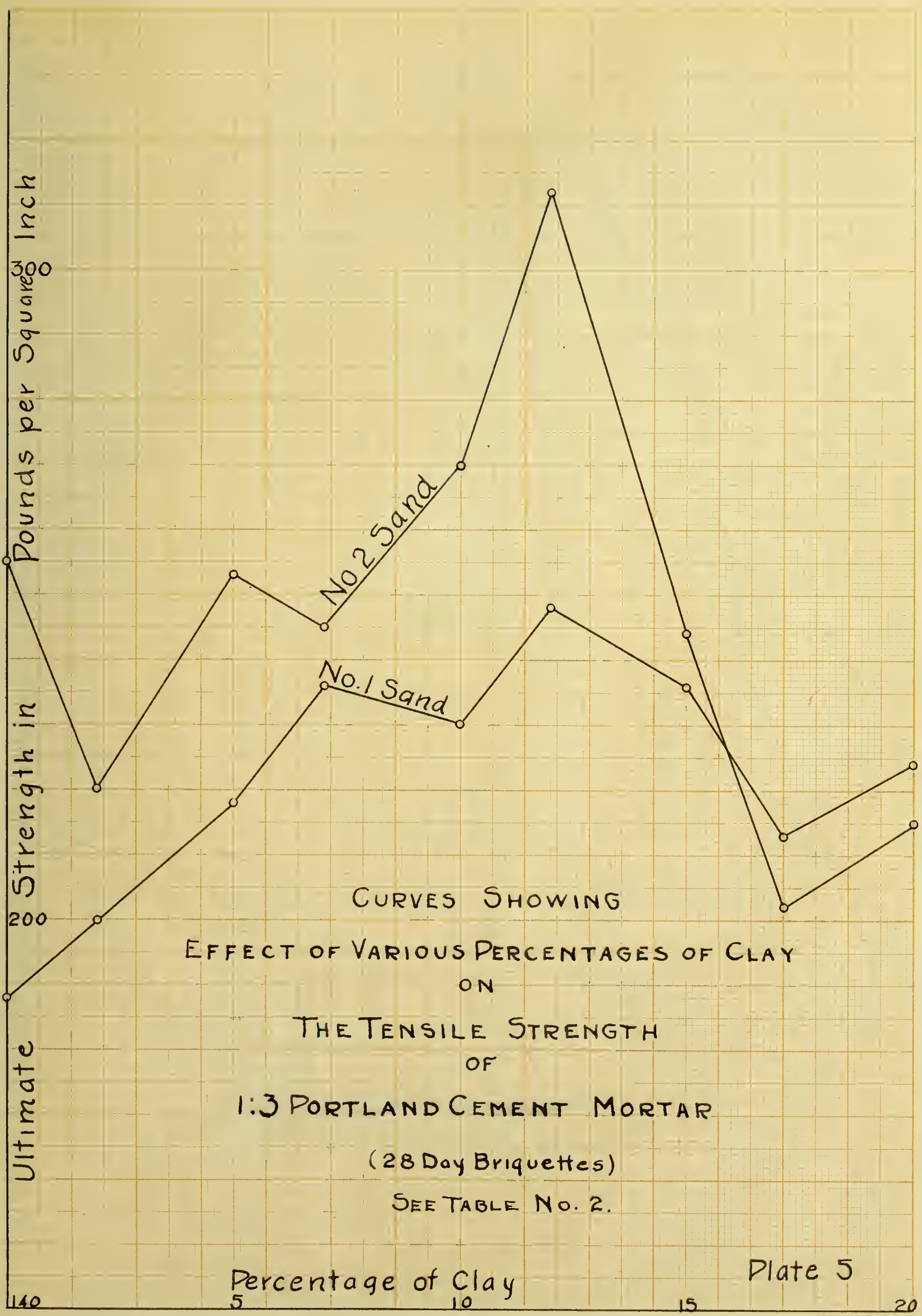
Plate 3



CURVES SHOWING
THE RELATION BETWEEN AGE & STRENGTH
OF
1:3 PORTLAND CEMENT MORTAR
CONTAINING
VARIOUS PERCENTAGES OF CLAY

MADE FROM No. 1 SAND
SEE TABLE No. 2.

Plate 4



CURVES SHOWING

EFFECT OF VARIOUS PERCENTAGES OF CLAY

ON

THE TENSILE STRENGTH

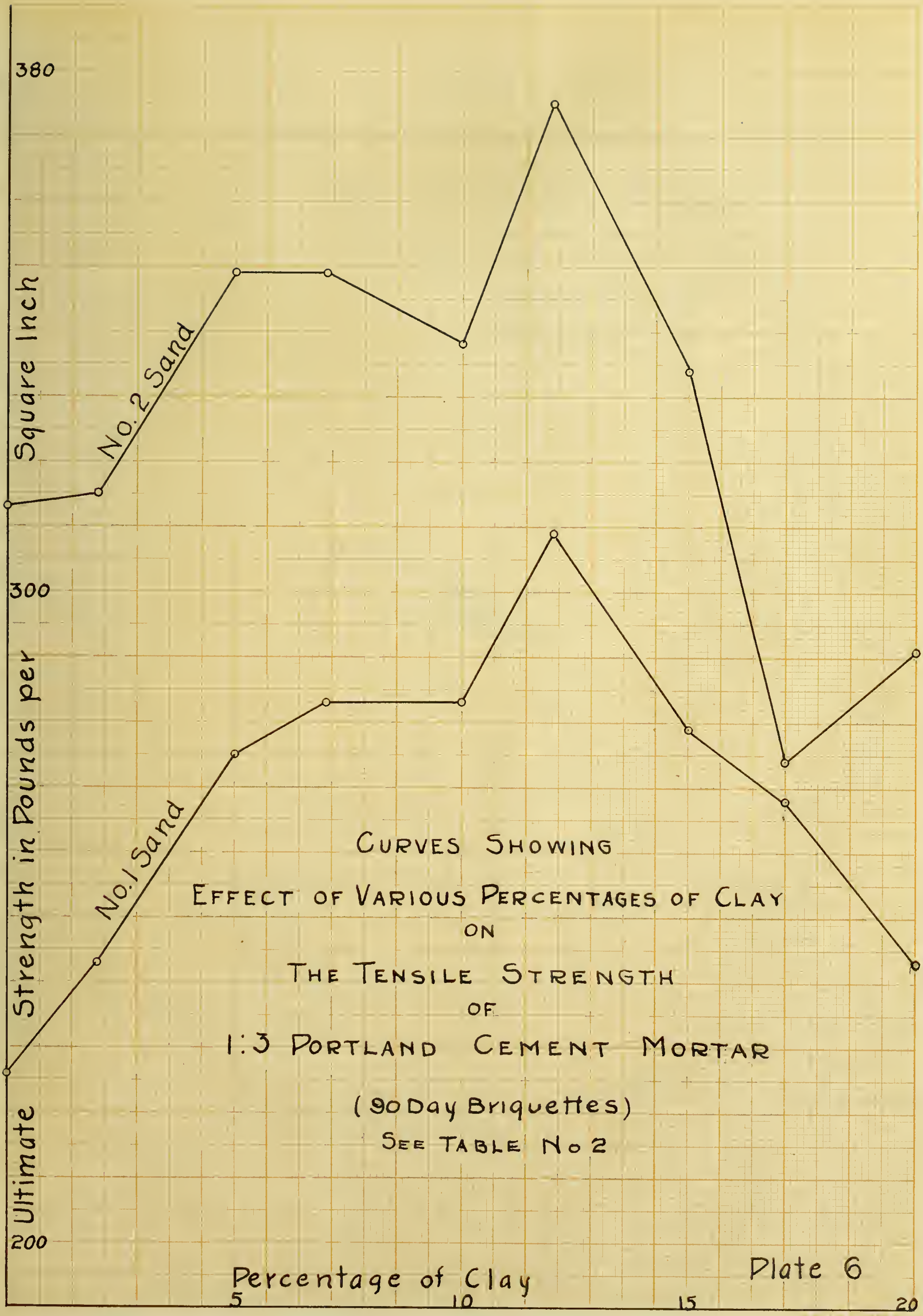
OF

1:3 PORTLAND CEMENT MORTAR

(28 Day Briquettes)

SEE TABLE NO. 2.

Plate 5



CURVES SHOWING

EFFECT OF VARIOUS PERCENTAGES OF CLAY

ON

THE TENSILE STRENGTH

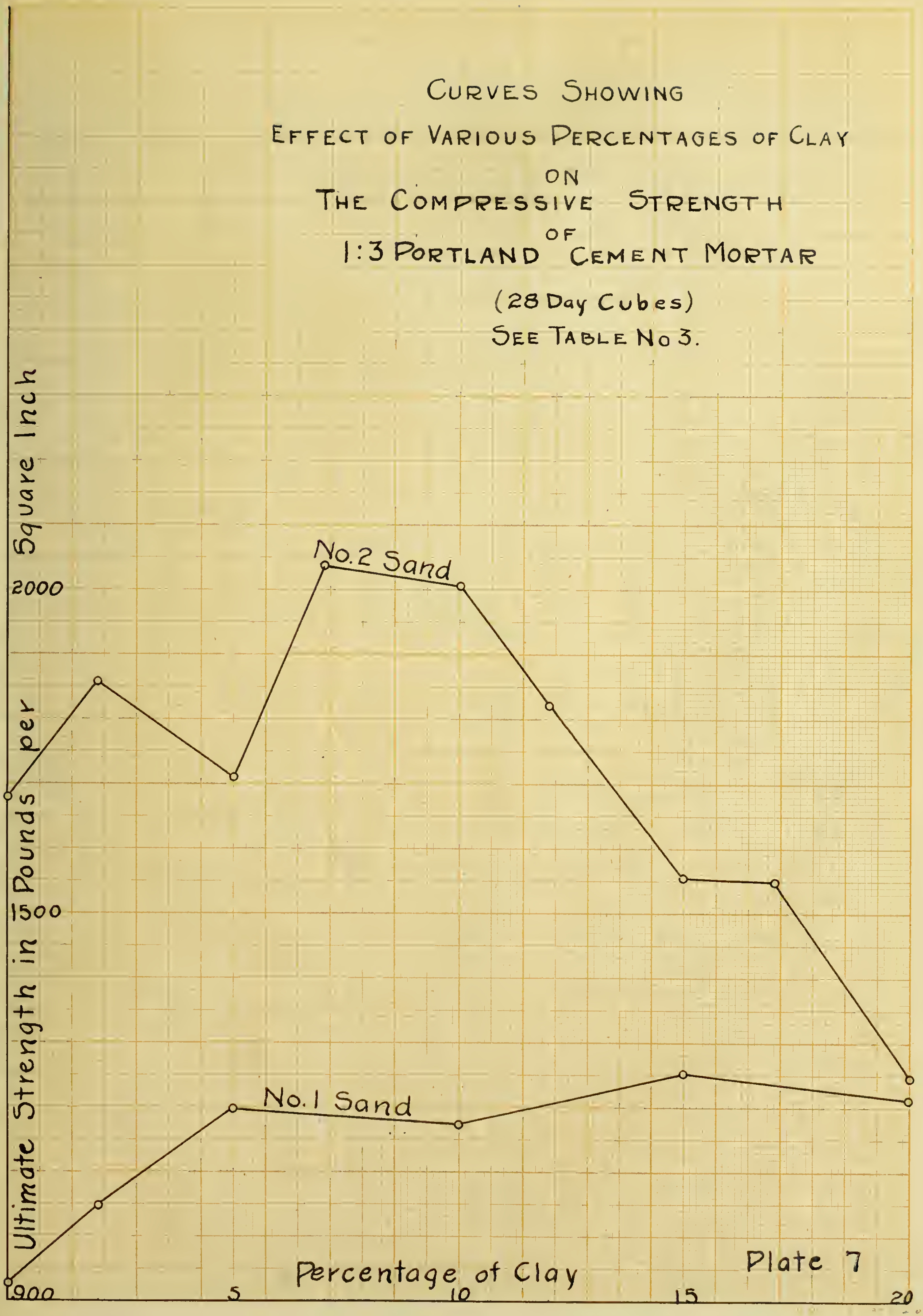
OF

1:3 PORTLAND CEMENT MORTAR

(90 Day Briquettes)

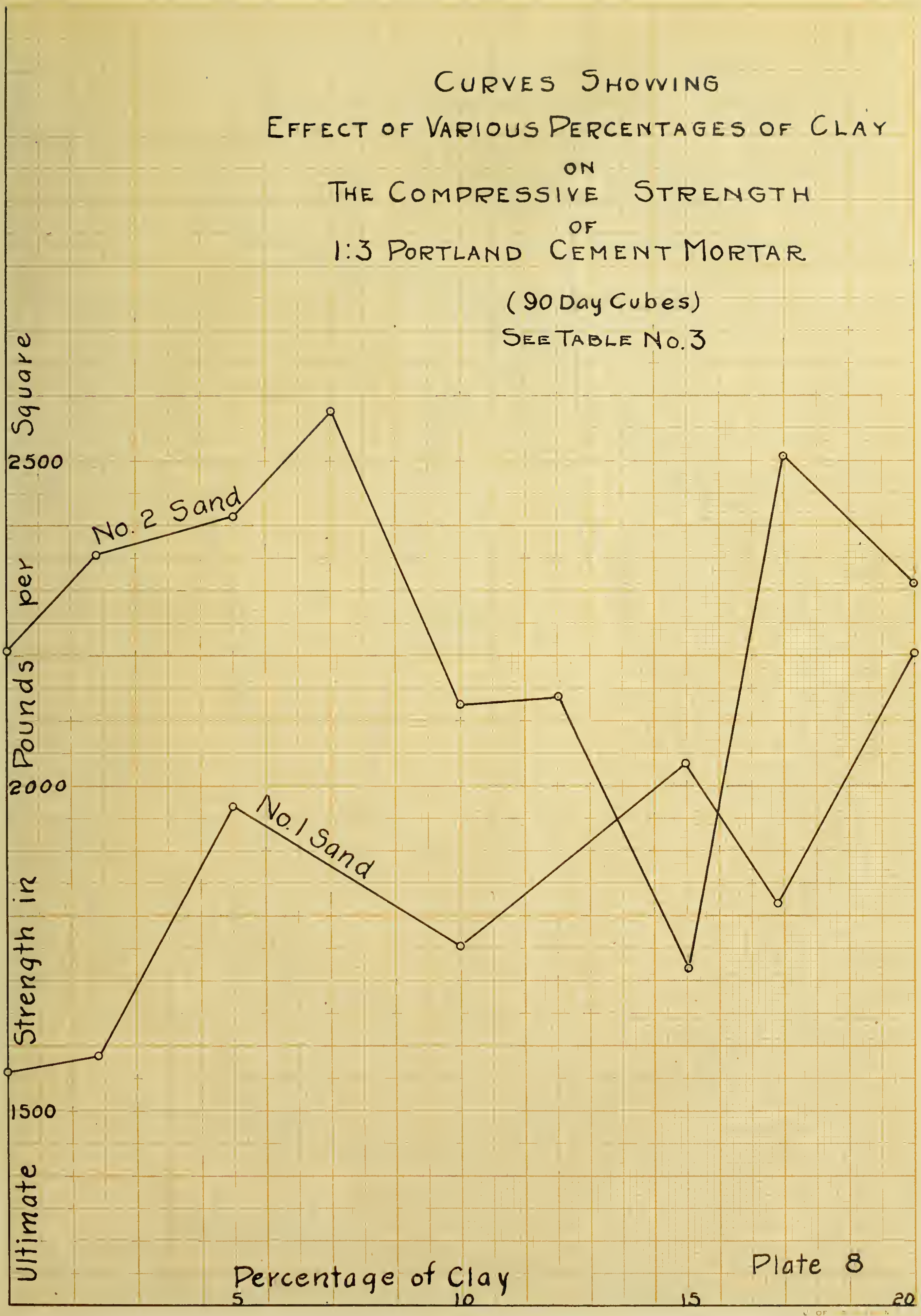
SEE TABLE No 2

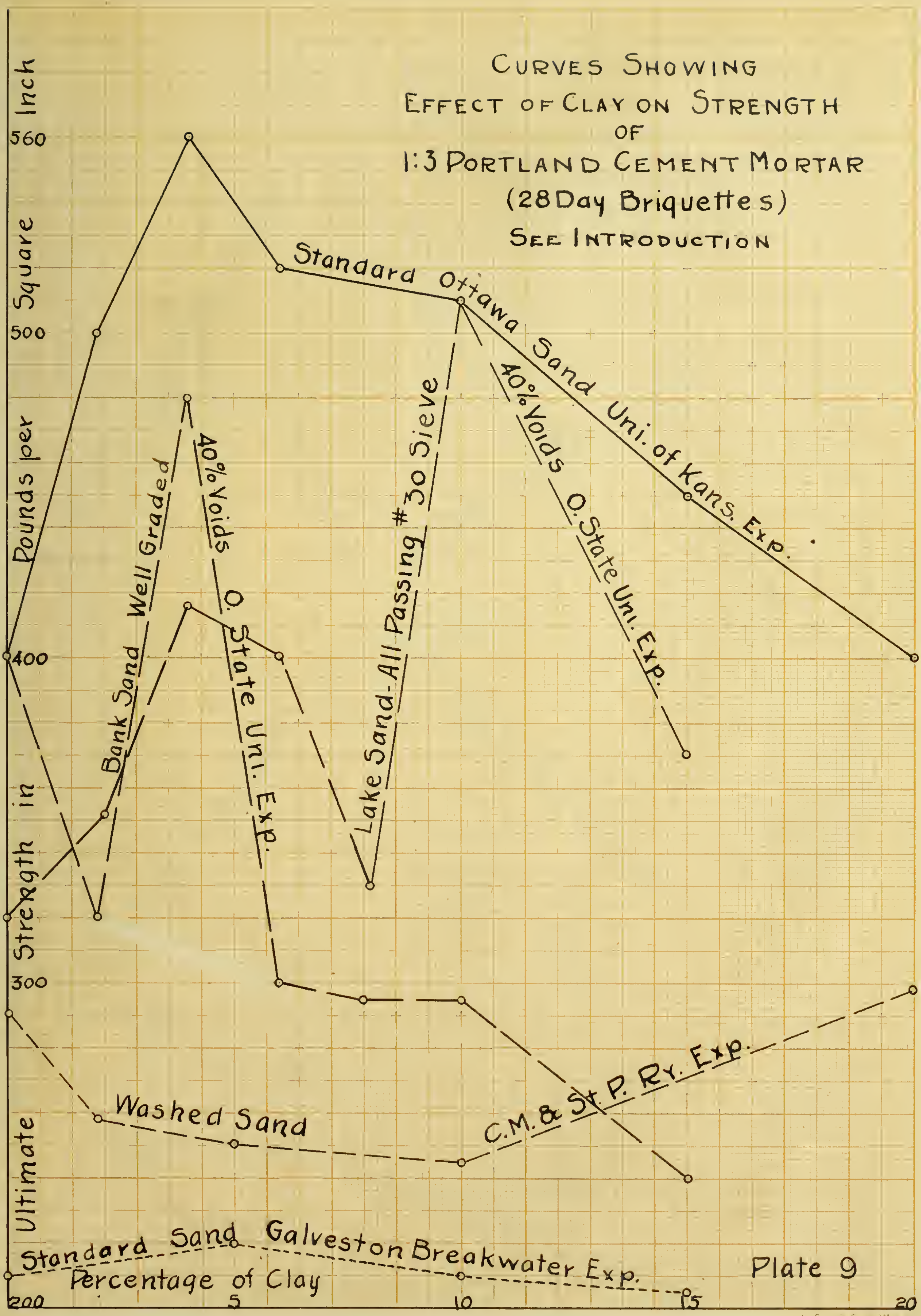
Plate 6



CURVES SHOWING
EFFECT OF VARIOUS PERCENTAGES OF CLAY
ON
THE COMPRESSIVE STRENGTH
OF
1:3 PORTLAND CEMENT MORTAR
(28 Day Cubes)
SEE TABLE NO 3.

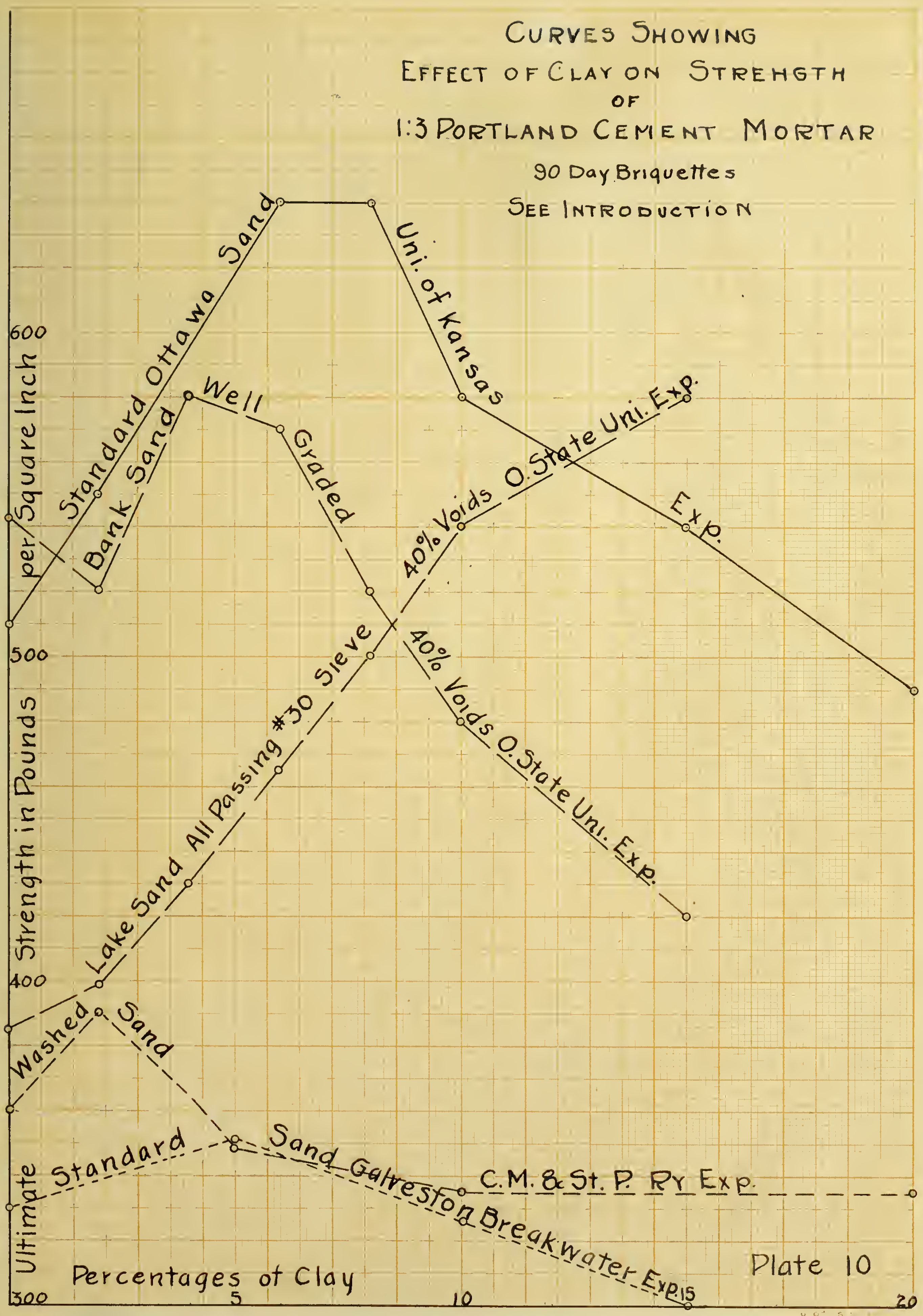
Plate 7





CURVES SHOWING
EFFECT OF CLAY ON STRENGTH
OF
1:3 PORTLAND CEMENT MORTAR
(28 Day Briquettes)
SEE INTRODUCTION

Plate 9



CURVES SHOWING
EFFECT OF CLAY ON STREHGTH
OF
1:3 PORTLAND CEMENT MORTAR
90 Day Briquettes
SEE INTRODUCTION

Plate 10

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